Lab One: Resistors in Series

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***Abstract*—An investigation into the voltages across resistors in series, when powered by a constant 5V source, was undertaken. First, a determination of the theoretical values given ideal components and conditions was completed. Then, experiments were run utilizing the components, a breadboard, a DC power supply and a DMM. Finally, a comparison was made between the ideal values and observed values.**

I. Introduction

THIS lab studies resistors in series, and the various measurements across them. It intends to verify Ohm's Law. It also intends to determine the maximum voltage that can be applied from the voltage source before a resistor suffers catastrophic failure. A schematic is below

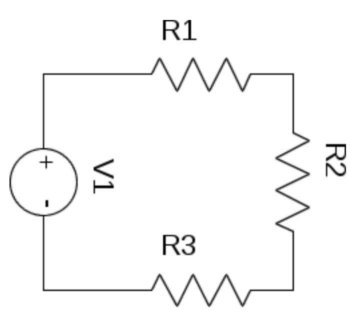

Fig. 1. Schematic

The ideal values, as determined by the given voltage and color-coded values on the resistors, are summarized in the following table

TABLE I
IDEAL COMPONENT VALUES

Component Name	Component Value
V1	5V
R1	3,600,000 Ω
R2	620 Ω
R3	2.2 Ω

II. Pre-lab Calculations

The current in the circuit must be calculated first. Observe that in series circuits, the current is the same across each element. This permits finding the current by regression to a simpler circuit.

$$
\begin{aligned}
I &= \frac{V}{\Sigma R} \\
&= \frac{V}{R1 + R2 + R3} \\
&= \frac{5\,V}{3,600,000\Omega + 620\Omega + 2.2\Omega} \\
&= 1.389\,\mu A
\end{aligned}
$$

The resulting voltages, powers, and current are summarized in the following table

TABLE II
IDEAL COMPONENT VOLTAGE, POWER, AND CURRENT

Component Name	Voltage	Power	Current
V1	5.000 V	6.945 μW	1.389 μA
R1	5.000 V	6.945 μW	1.389 μA
R2	.8612 mV	1.196 nW	1.389 μA
R3	3.056 μV	4.245 pW	1.389 μA

No resistor will exceed the maximum of .25 Watts based on these calculations.

The maximum working voltage formula is below (see Appendix for derivation)

$$
\begin{aligned}
V_{max} &= (R_1 + R_2 + R_3) \cdot \sqrt{\frac{.25W}{R_1}} \\
&= (3,600,000\Omega + 620\Omega + 2.2\Omega) \cdot \sqrt{\frac{.25W}{3,600,000\Omega}} \\
&\approx 948.8V
\end{aligned}
$$

III. Experimental Procedure

Follow the given procedure to collect the relevant data.

1) Using the DMM, measure the resistance in each resistor.
2) Using the DMM and its leads, the DC Power Supply and its leads, a breadboard, and the resistors, create the circuit described in Figure 1.
3) Using the DMM, measure the voltage across each resistor.
4) Return all materials to the appropriate locations in the laboratory.

IV. Collected Data

The following table shows the measured data and relevant calculations. Resistance and Voltage were measured using a DMM. Power was calculated using $P = V^2/R$ and current was calculated using $I = V/R$.

TABLE III
MEASURED COMPONENT RESISTANCE, VOLTAGE, POWER, AND CURRENT

Component Name	Resistance	Voltage	Power	Current
V1	NC	5.018 V	*6.955 μW	*1.394 μA
R1	3.62M Ω	5.017 V	6.95 μW	1.386 μA
R2	.61 kΩ	.847 mV	1.18 nW	1.389 μA
R3	2.3 Ω	.003 mV	3.91 pW	1.304 μA

*Calculated by summing the measured resistances and using the result as R in the formulas.

No resistor exceeded its .25 W power rating.

V. Comparison

The following formula is used to determine experimental error

Percent Error = $\frac{\text{observed value}-\text{ideal value}}{\text{ideal value}} \cdot 100$

TABLE IV
PERCENT ERROR

Component Name	Resistance	Voltage	Power	Current
V1	*NA	.36	.144	.360
R1	.556	.34	.072	-.216
R2	-1.61	-1.65	-1.34	0
R3	4.54	-1.83	-7.89	-6.12

*The resistance of the power source was never independently measured.

VI. Conclusion

Ohm's law has held within significant figures. The measurements of the resistors proved they were within tolerance. Observation of the error percentages shows a clear trend toward increased error further down the circuit. The placement of elements R2 and R3 further along the circuit, in combination with the fact that the strongest resistor was placed first in series, both contribute to these increased error percentages.

In addition, a suspected incorrect measurement of the voltage on R3, and the relatively large difference between the measured resistance of R3 and its ideal value, both contributed to higher errors on the power and current calculations of R3.

Appendix
Maximum Working Voltage Formula

First, observe the fact that components in series will share the same current. That is,

$$I_{total} = I_1 = I_2 = \cdots = I_n$$

Now, using Ohm's law and the formula for power, we can derive an expression for the power in a component. Consider

$$\begin{aligned} P_n &= I_n \cdot V_n \\ &= I_n^2 \cdot R_n \\ &= \left(\frac{V_{max}}{R_1 + R_2 + \cdots + R_n}\right)^2 \cdot R_n \end{aligned}$$

In our case with three resistors and R_1 absorbing most of the voltage, the formula looks like so

$$P = \left(\frac{V_{max}}{R_1+R_2+R_3}\right)^2 \cdot R_1$$

Our resistors have a maximum power rating of .25 Watts. Given this information, we can find the formula for the maximum working voltage with algebra

$$\begin{aligned} .25W &= \left(\frac{V_{max}}{R_1 + R_2 + R_3}\right)^2 \cdot R_1 \\ \frac{.25W}{R_1} &= \left(\frac{V_{max}}{R_1 + R_2 + R_3}\right)^2 \\ \sqrt{\frac{.25W}{R_1}} &= \left(\frac{V_{max}}{R_1 + R_2 + R_3}\right) \\ V_{max} &= (R_1 + R_2 + R_3) \cdot \sqrt{\frac{.25W}{R_1}} \end{aligned}$$